DOCUMENT RESUME

ED 218 147 SE 038 272

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TITLE The Hand-Held Calculator: Effects on Mathematical Abilities and Implications for Curriculum Change.
PUB DATE Jun 82
NOTE 45p.

EDRS PRICE MF01/PC02 Plus Postage.
DESCRIPTORS Annotated Bibliographies; *Calculators; Curriculum Development; Educational Research; Educational Technology; *Elementary School Mathematics; Elementary Secondary Education; *Mathematics Curriculum; *Mathematics Instruction; Secondary School Mathematics
IDENTIFIERS *Mathematics Education Research

ABSTRACT

This study consists of a review of research on calculator use in both elementary and secondary education. The bulk of this document consists of annotations of the research reviewed, and is categorized under three headings: 1) Calculator Effects on Computational Achievement and Attitude Toward Mathematics; 2) Calculator Effects on Problem Solving Ability; and 3) Implications for Curriculum Change. Among the conclusions reached, were: 1) There was enough evidence to believe that calculators were not detrimental to computational skills, and are more likely to improve them; 2) Children's attitudes did not suffer from using a calculator; and 3) Results regarding calculator effects on problem-solving performance were inconclusive. Teachers are seen to be largely unaware of what research has been done. Five specific recommendations are made related to calculator use in the classroom, the need for communication of research findings to communities and schools, and suggested directions for future investigations. (MP)

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THE HAND-HELD CALCULATOR: EFFECTS ON MATHEMATICAL ABILITIES AND IMPLICATIONS FOR CURRICULUM CHANGE

BY

PAUL O. SIGG

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Study directed

by

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Submitted in partial fulfillment of the requirements
for S591 in the School of Education
Indiana University at South Bend
June, 1982

SE 038 272

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INTRODUCTION

Computation has been the principle focus of elementary school mathematics education in America. During the 1960's there was a movement toward teaching the structure of mathematics which later came to be called the "modern mathematics" movement. Students were made to understand why a particular algorithm worked in an attempt to get them to understand the mathematics they were learning. If, however, a computational algorithm is thought of as nothing more than an efficient set of rules for finding a paper-and-pencil answer, then time spent showing children why an algorithm works contributes little toward a child's understanding of mathematics and it's applications (Wheatley, Grayson:37).

During the 1970's mathematics education in America experienced another well-defined movement, later labeled the "back-to-basics" movement. Calls for accountability and minimal competency placed even more emphasis on teaching basic facts and computational skills.

In 1973 a simple four-function calculator could be bought for $100. Today a comparable unit sells for under $5.00 ; and the declining cost has contributed to a rapid increase in their use. According to the 1977-78 NAEP mathematics assessment, over 75 percent of the sample had access to at least one calculator (Carpenter et al. 1981:34). The NIE/NSF sponsored Report of the Conference on Needed Research and Development on Hand-Held Calculators in School

Mathematics made reference to predictions that the 1980's would see the number of calculators approaching the number of automobiles in America (Conner:1).

In light of the availability of the hand-held calculator, what is the status of mathematics education in elementary schools today? A careful study of current mathematics texts used in elementary schools reveals that the curriculum is essentially computationally-based. Almost 40 percent of the average fifth-grade text is devoted to computation. In practice most classes are not able to complete the text, and the non-computational chapters are the first to be omitted. At the same time daily class work is being supplemented with worksheets providing additional computational practice (Wheatley, Grayson:37). Wheatley concluded that two years out of the first nine years of mathematics instruction are spent on teaching the division algorithm alone.

Given all the time devoted in elementary school to the teaching of computation, how do these students perform in testing situations? The second NAEP mathematics assessment revealed that thirteen-year-olds are not proficient in complex operations. Only 46 percent of the thirteen-year-olds could successfully find the quotient of a four-digit number by a two-digit number, and division computation did not improve between the ages of 13 and 17 (Carpenter et al. April, 1980:11).

In response to the calls from parents and school boards for competence in the basic computational skills, both the NCTM and the NCSM issued position statements on basic mathematical skills. The NCTM made this statement:

> Computational skills in isolation are not enough; the student must know when as well as how to multiply. We must address skills, but we must address them within a total mathematics program. (NCTM Position Statement on Basic Skills:18)

The NCSM expanded the definition of basic skills and cautioned that as society changes, so do ideas about which skills are basic. They predicted an increased emphasis on when and how to use calculators in mathematics (NCSM Position Paper on Basic Skills:21)

Because of the decreasing cost and the availability of calculators, national mathematics groups began to consider the role of calculators in teaching mathematics. The National Science Foundation (NSF), the National Institute of Education (NIE), and the National Advisory Committee on Mathematics Education (NACOME), as well as NCTM and NCSM, have recognized the potential of the hand-held calculator as an instructional tool and encouraged its use in the classroom. They have made calls for research to determine the appropriate use of calculators in the classroom and their effects. As early as September, 1974, the NCTM issued the following position statement:

> Mathematics teachers should recognize the potential contribution of this calculator as a valuable instructional aid. In the classroom, the minicalculator should be used in imaginative ways to reinforce learning and to motivate the learner as he becomes proficient in mathematics. (NCTM Instructional Affairs Committee:72)

The Board of Directors of the Instructional Affairs Committee adopted the following goal for the NCTM: "to encourage the development and evaluation of curriculum and instructional materials incorporating the use of the hand-held calculator and other computing devices." (Position Statements:71) In response to these calls, mathematics educators have explored the uses of the hand-held calculator in the classroom and have conducted studies to determine their effects on mathematical abilities.

STATEMENT OF THE PROBLEM

The availability of inexpensive calculators has forced a revolution upon school mathematics by eliminating the need for complex computional algorithms. No longer is it necessary to be proficient in paper-and-pencil computation in order to apply mathematics. Low cost and availability however, do not justify the use of calculators in school mathematics. Educators need to know what effect the use of the hand-held calculator will have on mathematical abilities and what changes, if any, are needed in the curriculum to exploit its use.

PURPOSE OF THE STUDY

The purpose of the study was to determine what effects the use of the hand-held calculator has upon mathematical abilities and thereby provide a summary of the research with recommendations to mathematics educators who are faced with the question of when and how to use calculators in their classrooms.

ORGANIZATION OF THE STUDY

The first part of the study examined thirteen studies dealing with the effects of calculator use on computational achievement and attitude toward mathematics. The second part of the study investigated nine studies of calculator effects on problem-solving ability. Annotations within both of these sections are arranged alphabetically.

The implications calculator use has for curriculum change is examined in the remainder of the study. Annotations within this section are arranged according to the following logical development:

--results from national assessment and the status of calculator use in schools;

--the current calculator controversy;

--recommendations from national mathematics groups.

DEFINITION OF TERMS

algorithm --"a step-by-step set of mathematical directions guaranteed to solve a specified type of problem," (Moursund:192).

basic skills --"fundamental skills that are the basis of later learning and achievement; not to be confused with 'minimum competencies'," (Thesaurus of ERIC Descriptors:23)

calculator --"electronic or mechanical device for performing mathematical or arithmetic operations," (Thesaurus of ERIC Descriptors:30).

CIC -- Calculator Information Center at Ohio State University. This center is presently directed by Marilyn Suydam and serves as a clearinghouse for research and related information on calculator use.

computation --"the act or method of calculating or estimating through the use of number operations and/or mathematical processes," (Thesaurus of ERIC Descriptors:47).

NACOME -- National Advisory Committee on Mathematics Education formed in 1974 to examine the status of mathematics teaching in grades K-12.

NCSM -- one of the affiliated groups of the NCTM, the National Council of Supervisors of Mathematics is an organization responsible for the direction and supervision of the mathematics program in a school district or school system.

NCTM -- National Council of Teachers of Mathematics.

NIE -- National Institute of Education (DHEW).

NSF -- National Science Foundation.

problem solving -- the process of finding the correct answer to a given problem (set of word statements along with a related question) whose solution is not immediately known.

ANNOTATIONS

CALCULATOR EFFECTS ON COMPUTATIONAL ACHIEVEMENT AND ATTITUDE TOWARD MATHEMATICS

Cech, J.P., "The Effect of the Use of Desk Calculators on Attitude and Achievement with Low-Achieving Ninth Graders," Mathematics Teacher 65:183-186, February, 1972.

This study was conducted during the 1969-70 school year, and was designed to determine if calculator use improves achievement and attitude toward mathematics. Nearly one hundred students with achievement scores two years or more below grade level comprised the sample. Four classes were divided into two treatment groups and given pre- and posttests. The experimental group was allowed to use calculators only to verify paper-and-pencil computation, and the control group used no calculators. Findings revealed that the use of calculators did not improve attitude toward math and did not improve computational skills. When students were allowed to use calculators on a second form of the posttest it was found that they computed better with calculators than without them. Note: Using calculators only to check paper-and-pencil work could be likened to pushing a bicycle to school and then riding it back home to verify that the distance was the same. How can attitude toward mathematics improve under these conditions?

Conner, Totsye J., An Investigation of the Use of Hand-Held Calculators by Students in Elementary School, Research Monograph No. 32, Educational Resources Information Center, ED 190 355,1980, 62 pp.

Kindergarten, second grade and fourth grade students were evaluated on achievement in problem solving, mathematics computation and concepts. A total of 325 students divided between an experimental group who used calculators and a control group who did not were tested at the end of one year in an attempt to answer the question: What effect does calculator use have on achievement? The data indicated that the experimental group scored higher than the control group in kindergarten; but there was no significant difference in achievement in second and fourth grade. Conner concluded that the calculator had no detrimental effect at the second and fourth grade levels and strongly underscored the need for long-term research in this area.

Creswell, John L, and Vaughn, Larry R., "Hand-Held Calculator Curriculum and Mathematical Achievement and Retention," Journal for Research in Mathematics Education 10:364-367, November, 1979.

The study reported in this article addressed the question of what materials are needed to take full advantage of the use of calculators in the classroom. Seventy-one students whose mathematics achievement was at least two years below grade level were divided into two treatment groups for a duration of eight weeks to test two null hypotheses: (1) There will be no significant difference between treatment groups in terms of achievement. (2) There will be no significant defference in terms of retention of skills. The control group used the traditional text approach and the experimental group used calculators along with specially designed curriculum materials. Students in the latter group used calculators on both post- and retention tests. The results indicated that the groups differed significantly in achievement in favor of the experimental group, and did not differ significantly with respect to retention.
Note: Most studies have revealed little, if any difference in achievement when calculators were used along with traditional text materials, which underscores the need to design special materials that exploit the use of the calculator.

Fehr, H.F.; McMeen, G.; and Sobel, M., "Using Hand-Operated Computing Machines in Learning Arithmetic," Arithmetic Teacher 3:145-150, October, 1956.

This half-year long experiment was conducted in the 1955-56 school year using hand-operated computing machines (forerunner of today's electronic calculator). Eight classes of fifth grade subjects were divided into two treatment groups to test only one hypothesis: students using computing machines will experience significantly higher gains in paper-and-pencil computation and reasoning ability over those not using the machines. Resultant data supported the hypothesis.
Note: Although subjects in this study did not use modern day hand-held calculators, the principles underlying the use of desk-top computing machines were felt by the investigator to be the same and warranted the study's inclusion in this annotated bibliography.

Gaslin, William Lee, "A Comparison of Avhievement and Attitude of Students Using Conventional or Calculator Based Algorithms for Operations on Positive Rational Numbers in Ninth Grade General Mathematics," Journal for Research in Mathematics Education 6:95-108. March 1975.

The goal of this study was to determine what effects a calculator-dependent algorithm had on mathematical achievement and attitude as compared to a conventional algorithm. The sample consisted of 110 students from two different schools and the duration of the study was ten weeks. Students received one of three different treatments (1) conventional textbook approach, (2) conventional text approach using calculators, and (3) an alternate algorithm approach where each fraction to be operated on was first converted to a decimal with the aid of a calculator. The results indicated that students using the alternate algorithm performed better that those using the conventional approach. Within the context of the conventional approach students did not benefit from the use of calculators. Retention of skills was significantly higher for the alternate algorithm treatment groups. Neither group proved superior in developing a positive attitude toward mathematics.

Moser, James M., The Effect of Calculator Supplemented Instruction Upon the Arithmetic Achievement of Second and Third Graders, Educational Resources Information Center, ED 180 764, National Institute of Education (DHEW), Washington, D.C., September, 1979, 353 pp.

This year-long study investigated the effects of calculators on the mathematics performance of primary school children. The design of the study used two treatment groups with posttesting that compared performance in the areas of computation and place value. The experimental group used calculators during instructional times, and the control group did not. Significant differences between groups at the second grade level were reported in the area of subtraction only, in favor of the experimental group. Significant differences were also reported at the third grade level in favor of the experimental group in the areas of place value and division only.
Note: The posttest used in this study was an experimenter-made arithmetic test as opposed to a standard achievement test usually used in similar studies.

Paasonen, Johannes, The Electronic Hand Calcuator in Finnish Comprehensive School Mathematics Teaching, Research Bulletin No. 53, Educational Resources Information Center, ED 201 468, Institute of Education, October, 1980, 62 pp.

This study investigated the possible effects of using calculators in mathematics teaching. The experiment involved 105 fourth grade students and compared two classes using calculators with three control groups. Instruction was well planned with calculators used in 25 percent of the lessons for checking results, and introducing new topics. A pretest/postest design was used to measure ability in computational performance, estimation, and understanding and application of mathematical principles, and to measure attitude toward mathematics. Results revealed significant differences favoring the experimental groups in areas of understanding, application and attitude. It was also found that the lowest ability group profited more from calculator use than the others.

PiRaart, Len, and others, 1980 Ohio Regional Conferences on Mathematics Education, Educational Resources Information Center, ED 200 421, National Science Foundation, Washington, D.C., 1980, 287 pp.

This document was a summary of the material disseminated at six regional conferences held in Ohio during 1980. The conferences were designed to provide teachers and others with problem solving and calculator experiences complete with materials, resources, strategies and summaries of research results. PiRaart listed 46 studies involving the use of calculators. Thirty-five of these were experimental, with the majority focusing on computational effects of using calculators. Problem solving received very little attention.

Rabe, Rebecca Moore, Calculators in the Mathematics Curriculum: Effects and Changes, Educational Resources Information Center, ED 204 178, June, 1981, 46 pp.

Rabe reviewed twenty-six calculator studies to determine what effect the hand-held calculator had upon mathematics learning and to assess what if any curriculum revisions were needed. In all but two studies, achievement gains in mathematical computation made by the experimental group using calculators were significantly as high or higher than gains made by the control group. Among other effects, calculators proved to be a positive motivator for students in all studies. Rabe recommended that less time be spent teaching complex algorithms, that calculators be introduced into the mathematics curriculum after basic facts are learned, and that estimation skill be taught as a well-defined procedure.

Roberts, Dennis M., "The Impact of Electronic Calculators on Educational Performance," Review of Educational Research 50:71-98, Spring, 1980.

Roberts reviewed thirty-four calculator studies concerning the effects of calculator use on mathematics attitudes and achievements. The typical research design used pre-and posttesting with two treatment groups: an experimental group who was allowed to use calculators during the treatment period and a control group who was not. Overall results revealed significant differences in computation in favor of calculator use. There were little or no difference between groups with respect to mathematics concepts or general attitudes toward mathematics. Roberts noted that 47 percent of the investigations did not allow the use of calculators on posttests, revealing what he called a "negative orientation"--will the use of calculators during instruction harm student performance using paper-and-pencil algorithms? The author suggested that using the calculator on the posttest would be a positive and more effective research strategy. Roberts also pointed out the need for research of the cross-sectional or longitudinal design as to the timing for introducing calculators into the mathematics curriculum.

Rudnick, Jesse A., and Krulik, Stephen, "The Minicalculator: Friend or Foe?" Arithmetic Teacher 23:654-656, December, 1976.

The Mathematics Education Action Research Center at Temple University (MEARC) conducted an experiment with 600 seventh grade students, which began in September,1975 and continued for the entire school year. MEARC staff which included Rudnick and Krulik designed the study to ascertain what effect the use of the hand-held calculator had upon total mathematics achievement and upon paper-and-pencil basic skills. Calculators were not used on the pre-and posttests. The authors reported that both, the control and experimental groups demonstrated growth in overall achievement and ability to perform paper-and-pencil operations. The experimental group showed a slight gain in both areas over the control group.

Schnur, James O., and Lang, Jerry W., "Just Pushing Buttons or Learning?--A Case for Minicalculators," Arithmetic Teacher 23:559-562, November, 1976.

Schnur and Lang conducted an investigation to reveal any differences in mathematical computational ability between experimental groups using calculators and control groups which did not after four weeks of instruction. The authors designed the experiment to also determine whether or not sex or ethnic/economic background were factors in the scores of either calculator or non-calculator groups. Sixty students ranging in age from 9 to 14 who were enrolled in a summer remedial program constituted the sample. Schnur and Lang wanted to determine specificly if any increased ability on the part of the experimental groups would transfer to a posttest situation when the students were not permitted to use the calculator. The results indicated that the experimental groups did gain significantly more computational ability, but that there were no significant relationships between sex and calculator or non-calculator usage, and between ethnic/economic background and calculator or non-calculator usage.

Shumway, Richard J., and others, "Initial Effect of Calculators in Elementary School Mathematics," Journal for Research in Mathematics Education 12:119-41, March, 1981.

This year-long study was designed to simulate an initial first-year use of calculators in elementary school mathematics. Fifty teachers and 1500 students in grades 2 to 6 from five different states made up the sample. In order to evaluate a typical first level use of calculators, calculators and calculator resource materials were made available to teachers and students, but no program of instruction was prescribed. The experimental, two treatment group design with pre-and posttesting was used. Results revealed no significant detrimental or positive effects for teaching mathematics associated with calculator use. The authors noted that calculators were an aid to introducing new topics such as decimals and negative integers earlier in school mathematics and that calculators did improve student and teacher attitude toward mathematics. Shumway and others recommended that calculators be used in schools if time is given to select appropriate activities for their use. The authors recommended that the possible deletion of division and other complex algorithms in preference to calculators, be considered as a needed next step.

Standifer, Charles E., and Maples, Ernest G., "Achievement and Attitude of Third-Grade Students Using Two Types of Calculators," School Science and Mathematics 81: 17-24, January, 1981.

Responding to the need for research involving the use of calculators with primary students, Standifer and Maples designed this study to compare the effectiveness of two types of calculators upon learning and retaining mathematics skills, and upon attitude toward mathematics. The calculators used were the traditional hand-held calculator and a programmed-feedback calculator called the "Little Professor". The hand-held calculator was found to be more effective in computational skill and in total mathematical achievement. There was also evidence which indicated that the programmed-feedback calculator was superior to the traditional no-calculator approach in the learning of computational skills, but not in the retention of those skills.

West, Tommie A., "The Effectiveness of Two Drill Strategies (Paper and Pencil, Electronic Calculator) in Facilitating the Learning of Basic Multiplication Combinations with Factors of 7, 8, or 9," School Science and Mathematics 80:97-102, February, 1980.

West designed an experiment to compare the effectiveness of teaching basic multiplication facts using two strategies: ordinary paper-and-pencil drill and an electronic calculator called "Matheputer" that presents problems at random to the user and supplies immediate feedback as to the correctness of the response. Ninety children in grades 4 through 6 were involved. To the author's surprise, the paper-and-pencil strategy proved more effective in teaching basic multiplication facts than using an electronic calculator. Note: The calculator used was a programmed-feedback device rather than the traditional hand-held calculator.

Whitaker, W.H., "A Study of Change in Achievement, Interest, and Attitudinal Variates Accompanying the Use of Electronic Calculators in a First Grade Mathematics Curriculum," Dissertation Abstracts International 38A:97-98, July, 1977.

This study involved all first grade classes in one building and was designed to ascertain the effects calculator use had upon achievement, attitudes, and mathematics related interests. Students were randomly assigned to two groups: the experimental group which used calculators to check their answers to worksheets and a control group whose answers were checked by a teacher. The groups were pre- and posttested with two achievement instruments and one attitudinal scale. The author drew the following conclusions based on test data: calculators aided students in computation and verbal problems, and instruction using calculators is no less effective than instruction without in terms of overall mathematical achievement and attitude gain.

CALCULATOR EFFECTS ON PROBLEM SOLVING ABILITY

Anderson, Lyle Eugene, "The Effects of Using Restricted and Unrestricted Modes of Presentation with Electronic Calculators on the Achievement and Attitude of Seventh Grade Pupils," Dissertation Abstracts International 37A:6321-6322, April, 1977, 140 pp.

This study investigated the effectiveness of restricted and unrestricted calculator use on attitude toward mathematics, mathematical achievement, understanding of concepts, computational skill, and problem-solving ability. The sample consisted of 367 pupils, and the duration of the study was twenty weeks. The students were divided into three treatment groups: (1) a restricted group using the calculator only to check paper-and-pencil computation and to aid in developing problem-solving concepts, (2) an unrestricted calculator use group, and (3) a control group using no calculators. The results indicated that no changes occurred among the three groups in mathematics achievement, computational skill, or understanding of concepts. Allowing the unrestriced use of calculators did improve attitude toward mathematics. Allowing restricted calculator use did improve problem-solving ability. On untimed tests students using calculators correctly solved problems twice as fast as those not using calculators. Anderson recommended that calculators be placed in seventh grade regular mathematics classes without curriculum changes.

Boling, Mary Ann Neaves, "Some Cognitive and Affective Aspects of the Use of Hand-Held Calculators in High School Consumer Mathematics Classes," Dissertation Abstracts International 38A:2623-2624, November, 1977, 73 pp.

Boling investigated the effects of hand-held calculators on mathematical verbal problem solving and on attitudes toward mathematics. The sample consisted of ninety-four twelfth grade consumer mathematics students divided into two groups: calculator and paper-and-pencil. Calculators were used to perform all computations. The duration of the study was nineteen weeks. Pre- and posttests were given to measure changes in achievement or attitude toward mathematics. Results indicated no significant differences in achievement in verbal problem solving or attitude towards mathematics between experimental and control groups. Teachers involved in the study made the following observations: calculators enabled more material to be covered, encouraged cooperation between students, and improved classroom discipline.

Blume, Glendon W., and Mitchell, Charles E., The Calculators Effect on Children's Solution Processes, Educational Resources Information Center, ED 170 166, 1979, 41 pp.

To investigate the effect of calculator use on students' solution methods of mathematics problems, three preliminary studies and one main study were conducted on the elementary, middle and secondary school levels. Routine mathematical problems were given to students for which there were both a longer and shorter method of solution. The results indicated a significant association between the choice of the shorter solution method and paper-and-pencil use. Longer solution methods were associated with hand-held calculator use. Calculators proved to inhibit rather than enhance a student's search for potential simplifications and alternative solutions. Another finding was that paper-and-pencil produced more computational errors, and calculators produced more errors involving chaining of operations.
Note: Blume and Mitchell concluded that instruction designed to encourage students to search for simplification and shorter methods (to think before they compute) should accompany calculator use.

Hopkins, B.L., "The Effect of a Hand-Held Calculator Curriculum in Selected Fundamentals of Mathematics Classes," Dissertation Abstracts International 39A: 2801, 1978.

This investigation was designed to determine the effects calculators have on computational achievement, problem-solving achievement, and attitude toward mathematics. During the Fall of 1977, twelve classes of ninth grade general mathematics students from three high schools were divided into two treatment groups for a duration of four weeks. Both groups received equal instruction in estimation, computation, and problem solving, but the experimental group used calculators. Data from pre-and posttesting indicated that students using calculators experienced gains equal to those students not using calculators, and achieved significantly higher gains in problem solving. It was also found that when students were allowed to use a claculator on the posttest, they achieved significantly higher gains in both computation and problem solving. No significant differences were discovered between groups with respect to attitude.

Kasnic, M.J., "The Effect of Using Hand-Held Calculators on Mathematical Problem Solving Ability Among Sixth Grade Students," Dissertation Abstracts International 38A:5311, March, 1978.

Sixth grade students from four schools were assessed as to their problem-solving ability and were placed in low, average, and high ability groups. Randomly selected students from each group underwent nine sessions of practice problem solving and were then given a problem-solving ability posttest. Each school was assigned a different treatment: one school used calculators in the practice sessions only, one school used calculators in the practice sessions and on the posttest afterwards, one school used paper-and-pencil only throughout, and one school served as a control group and did not undergo any problem-solving treatment. An analysis of the practice sessions revealed that groups using calculators did not solve significantly more problems than the group without calculators. There was also no significant difference in posttest scores between the treatment groups.

Lowerre, George F., and others, "Using Electronic Calculators with Third and Fourth Graders: a Feasibility Study," School Science and Mathematics 78:461-464, October, 1978.

Lowerre reported on a small experiment conducted using the hand-held calculator with five pupils in grades 3 and 4 and designed to explore ways to effectively use calculators at this grade level. The subjects were tested before and after a ten week instruction period using the Metropolitan Achievement Test (MAT). Test results revealed seven months to two years gain in total mathematical ability. Two of the three pupils tested experienced one year gains in problem-solving ability. These results were somewhat discounted by the following limitations of the study: (1) Small group or one-to-one instruction is atypical of the elementary classroom environment, (2) The MAT gives heavy emphasis to addition and multiplication tables and much time was given to practicing these tables during the treatment period. As a result of this study, Lowerre noted the following implications of the calculator for problem-solving situations: (1) Students are able to receive substantially more practice with real world problems, (2) Teaching emphasis can be shifted from computation to problem-solving techniques. The author recommended that estimation skills, decimals, and negative numbers be taught at an earlier time in the curriculum.

Sulliven, John J., "Using Hand-Held Calculators in Sixth Grade Classes," Arithmetic Teacher 23:551-552, November, 1976.

The Bureau of Mathematics Education, New York State Education Department organized classroom trials of calculators in two sixth grade classes during the school year, 1973-74. The goal was to determine if and how calculators could improve the regular mathematics program. The article made no mention of pre- or posttesting, although a "project statistical analysis" revealed that calculators did not improve verbal problem-solving skills. Sullivan noted that the most powerful impact of the calculator in this study was its ability to motivate interest in decimal fractions, and their relationship to common fractions.

Suydam, Marilyn N., The Use of Calculators in Pre-College Education: A State-of-the-Art Review, Educational Resources Information Center, ED 171 573, Calculator Information Center, Columbus, Ohio, May, 1979.

Suydam stated that over 100 studies between 1975 and 1978 had been conducted, and in all but a few cases achievement was as high or higher when calculators were used for instruction (but not for tests) than when they were not. The author also mentioned that some research had explored the role of the calculator in problem solving, and cited one study (Hopkins 1978) where the hand-held calculator helped ninth grade basic mathematics students achieve higher problem solving scores.

Vannata, Glen D., and Hutton, Lucreda H., "A Case for the Calculator," Arithmetic Teacher 27:30-31, May, 1980.

During the 1976-77 school year the Indianapolis Public School System conducted a project with about 1000 students and all teachers of grades 4 to 6 to investigate the effects of the hand-held calculator on problem-solving performance and attitude toward mathematics. Calculators were incorporated into the mathematics curriculum and used for textbook and out-of-text problem solving, practice with large numbers, and to reinforce computational skills. In a posttest (California Achievement Test) administered at the end of the year, calculator classes scored well above expected gains in computation and problem applications. Sixth grade students gained significantly in problem-solving performance. Note: For this project, a guide correlating the use of the hand-held calculator with the classroom mathematics text and other calculator oriented materials were provided each teacher. In light of the project results it was felt by the authors that to successfully incorporate calculators into the curriculum, material must be provided that correlates with the local mathematics program.

Wheatley, Charlotte L., "Calculator Use and Problem-Solving Performance," Journal for Research in Mathematics Education 11:323-34, November, 1980.

The purpose of this study was to assess the problem-solving performance of sixth graders with and without the use of calculators to determine which group used a wider range of problem-solving strategies, made fewer computional errors, and solved more problems correctly. Forty-four subjects were randomly assigned to one of two classes. Each class was daily taught problem-solving techniques for six weeks. The calculator group was directed to use calculators on all assignments. Each group was then tested with an individual interview session involving the solution of five word problems. Individuals in the calculator group were allowed to use calculators during their interviews. The results revealed that the calculator group used significantly more problem-solving processes than did the non-calculator group. The non-calculator group subjects committed over two times as many computational errors. These results suggested that calculators allow students to focus more on problem-solving strategies and less on computation.
Note: Students with above average ability were used in the study. Over 50 percent of the subjects were above the ninetieth percentile on the mathematics section of the Iowa Test of Basic Skills.

IMPLICATIONS FOR CURRICULUM CHANGE

Carpenter, Thomas P., and others, "Results and Implications of the Second NAEP Mathematics Assessment: Elementary School," Arithmetic Teacher 27:10-12, 44-47, April,1980.

The authors summarized the major results of the content areas and made conclusions based on their analysis of the data from the exercises. The NAEP exercises were administered to a carefully selected sample of over 70,000 students, ages 9, 13, and 17. Students generally performed well on simple one-step word problems, but poorly on multi-step and non-routine word problems. Computational performance changed little from the last national assessment, but performance on certain word problems dropped significantly. The following specific result reported by Carpenter et al. interested this investigator. About 70 percent of the thirteen-year-olds could successfully find the quotient of a three-digit number by a one-digit number , but performance dropped to 46 percent on a four-digit number divided by a two-digit number. The authors indicated that unlike all the other operations there was no improvement between the ages of 13 and 17 on division computation.

Carpenter, Thomas P., and others, "Results and Implications of the Second NAEP Mathematics Assessment: Secondary School," Mathematics Teacher 73:329-338, May, 1980.

This article reviewed the results of the second NAEP mathematics assessment. Overall student performance on skill and understanding exercises suggested that computational skill development and conceptual understanding are closely linked together; that is, students who demonstrated good knowledge of area and volume concepts also performed well on exercises in computing area and volume. The greatest single lack revealed by the assessment which showed up at all grade levels and in all content areas was problem-solving skills. Rather than carefully thinking about how to solve a problem, most students simply applied one of the four arithmetic operations to the numbers given in the problem. The results also revealed that students did not use basic problem-solving strategies such as drawing a diagram or checking for the reasonableness of answers.

Carpenter, Thomas P., and others, "Calculators in Testing Situations: Results and Implications from National Assessment," Arithmetic Teacher 28:34-37, January, 1981.

The 1977-78 mathematics assessment of the National Assessment of Educational Progress (NAEP) attempted to determine how well students performed mathematics problems in a test situation while using a hand-held calculator. Although students using calculators took longer to do the problem than when using paper-and-pencil, the results indicated that students scored substantially higher for subtraction, multiplication and division computations at all age levels tested. The authors raised the questions: Should paper-and-pencil algorithms continue to be taught in school? Should more time be spent teaching estimation to determine reasonableness of answers? Students using either method, paper-and-pencil or calculator, experienced difficulty in division with distinguishing dividend from divisor. On test items requiring problem-solving techniques performance of students was poorer with a calculator than without for some age groups; and a high percentage of students using calculators failed to give answers to the problem-solving type exercise. The authors remind educators of the need to teach problem-solving strategies that take full advantage of the calculator, and that calculators do not solve problems, people do.

Wyatt, J. Wendell, and others, "The Status of Hand-Held Calculator Use in School," Phi Delta Kappan 61: 217-218, November, 1979.

This article reported the results of a survey conducted during the Spring of 1979 of ten school districts in the state of Missouri. According to the survey, almost 70 percent of the students had access to at least one calculator for school use. Over 80 percent of the teachers thought calculators should be make available to students in school, but less than 3 percent said their schools had made them available. Of the teachers who had not used calculators, most were aware of using the calculator as a computational tool and as a means to check paper-and-pencil algorithms. Few were aware of any potential use for instruction. No teacher was familiar with what research had been done on calculators. Most teachers were either unaware, or wary of the effects of calculator use on children's ability to compute or remember basic facts. The authors called for the following prerequisites for the effective use of calculators in the classroom: (1) administrative leadership and support, (2) teacher training in the effective use of calculators, (3) dissemination of calculator materials, and (4) immediate communication of calculator research to the school and community.

Scandura, Alice M., and others, "Using Electronic Calculators with Elementary School Children," Educational Technology 16:14-18, August, 1976.

During the Summer of 1974 the authors conducted a series of mini-experiments to explore the uses and the effects of the hand-held calculator with primary age children. No formal evaluation instruments were used. The authors reported the following observations, the first one considered by them to be most important: (1) calculators provided continual motivation, (2) calculators increased attention span, (3) children using calculators were more interested in creating their own problems and participated in mathematical activity more often on their own time, and (4) children using calculators made frequent discoveries independently.

Shumway, Richard J., "Hand Calculators: Where Do You Stand?" Arithmetic Teacher 23:569-572, November, 1976.

Shumway details arguments for and against the use of hand-held calculators in school mathematics. The major arguments for using calculators were: calculators (1) will make paper-and-pencil algorithms obsolete, (2) will not be expensive, (3) can be used to teach mathematical concepts and problem solving, (4) will shift the focus from how to compute to when and what operation to use, (5) will provide more time to teach mathematics in depth and introduce new topics. Some of the arguments against using calculators were: calculators (1) will interfere with the learning of basic facts, (2) are not appropriate tools for slow learners, (3) will reduce a child's ability to detect errors, (4) would discourage mathematical thought, (5) will meet with great opposition from parents.

"National Council of Teachers of Mathematics Position Statement on Basic Skills," Arithmetic Teacher 25: 18, October, 1977.

This statement was made in response to the "back-to-basics" movement which called for competence in the basic computational skills. The NCTM communicated its position on basic mathematical skills with the following excerpt taken from their position statement: "Computational skills in isolation are not enough; the student must know when as well as how to multiply. We must address skills, but we must address them within a total mathematics program." The NCTM also declared that the hand-held calculator emphasized this need for understanding because one must know when to push what button.

Pollak, Henry O., "Hand-Held Calculators and Potential Redesign of the School Mathematics Curriculum," Mathematics Teacher 70:293-296, April, 1977.

Pollak commented upon the unrestrained enthusiasm over the hand-held calculator, and urged mathematics educators to dake a deeper look at this device from the viewpoint: What are some of the most difficult problems encountered in teaching school mathematics which could be helped by the calculator? The author cited several examples from the school mathematics curriculum where calculators could be exploited and suggested that calculator availability could alter the ordering of mathematical topics within the curriculum. Pollak also stated that calculators would allow us to introduce many topics earlier than what they are now presented.

Etlinger, Leonard, "The Electronic Calculator: A New Trend in School Mathematics," Educational Technology 14: 43-45, December, 1974.

Etlinger described two different views on the use of the calculator, a "functional" view and a "pedagogical" view. According to the purely functional view the calculator serves as a classroom device much like an eraser or desk. In this view the calculator would do all the arithmetic chores, saving time and the trouble of learning and using the traditional paper-and-pencil algorithms for division, multiplication, carrying and borrowing. The purely pedagogical view looks at the calculator as a manipulative device much like flashcards, or a textbook--a device to facilitate rather than replace learning. Etlinger underscored the need for research that would determine the value of the calculator as a pedagogical instrument. The author was concerned about whether the availability of a calculator would cause a child to think about more or fewer different methods to solve a problem.

Gawronski, Jane Donnelly, and Coblentz, Dwight, "Calculators and the Mathematics Curriculum," Arithmetic Teacher 23:510-512, November, 1976.

Gawronski and Coblentz stated that low cost and availability does not justify using calculators in the classroom and underscored the need to know if the use of calculators will promote the understanding and achievement of the mathematical objectives presently being taught or if they will necessitate curriculum changes. The authors recognized that calculators could change the current mathematics curriculum if they were looked upon as purely functional tools and allowed to do all arithmetic computations. (A new objective could be to find the product of two three-digit numbers by using a calculator.) The authors stated that students must command some minimal level of computational skill independent of machine support; but that unnecessary time consuming calculations could be detrimental to a child's interest in mathematics. The calculator would eliminate this chore and provide more time to develop problem-solving skills.

Usiskin, Zalman, "Are Calculators a Crutch," Mathematics Teacher 71:412-413, May, 1978.

The author addresses the premise that if you allow children to use calculators for routine arithmetic problems, then these children will eventually be unable to do arithmetic without the aid of a calculator. Usiskin cited data from the NAEP studies to substantiate the fact that despite the heavy emphasis on arithmetic in the first eight years of school and in high school remedial mathematics courses, that an estimated 40 percent of the students entering high school are not adequately skilled in arithmetic to enter first-year algebra. The author stated that if the critical issue is not how the computation is done, but rather knowing when and what arithmetic to use to solve problems; then insisting that all students learn paper-and-pencil algorithms is placing the emphasis incorrectly on the means, rather than the ends, of computation.

Bell, Max S., "Calculators in Elementary Schools? Some Tentative Guidelines and Questions Based on Classroom Experience," Arithmetic Teacher 23:502-509, November, 1976.

The author and a group of teachers explored the classroom uses of calculators under a NSF grant. This article reported some of their conclusions based on informal work in about twenty classrooms. It was the authors intention to sort out some of the issues classroom teachers will encounter in using calculators. The following two issues in the form of questions were answered. Do children detect errors and reject unreasonable results? The authors found that most students did not have good number sense and accepted whatever results they got with or without a calculator. Do children become dependent on calculators? The classroom explorations revealed that children initially exposed to calculators do all problems on them, but very quickly learn good discernment about doing routine problems in their head whenever possible.

"National Council of Supervisors of Mathematics Position Paper on Basic Skills," Arithmetic Teacher 25:19-22, October, 1977.

To meet the need of mathematics education for a unified position on basic mathematical skills, and to appropriately expand the definition of basic skills, the NCSM formulated and published this position paper. This paper denounced the narrow definition of basic skills, "which equates mathematical competence with computational ability"(:19) and stated that computational skills in isolation contribute little to one's ability to function in society. The NCSM listed ten basic skill areas and emphasized that appropriate computational skills combined with the other nine skill areas would adequately equip the learner with the mathematical ability needed as an adult. Note: NCSM cautioned that as society changes, so do ideas about which skills are basic. They alerted the reader to the fact that there will be an increased emphasis on when and how to use calculators in mathematics.

Bell, Max S., "Calculators in Secondary School Mathematics," Mathematics Teacher 71:405-410, May, 1978.

In this article Bell outlined a position supporting calculator use in schools. He stated that people outside of education may soon use only calculators to do what now makes up the core of the first eight years of mathematics schooling. Bell cited several aspects of education sure to be effected by the use of the calculator and singled out computation to be that part of the curriculum most resistant to change. Bell also quoted from several reports including the Report of the Conference on Needed Research and Development on Hand-Held Calculators in School Mathematics, 1976. That conference made twenty-two recommendations, of which several specificly dealt with curriculum development. Recommendations 6, 8, and 10 called for curriculum materials to be developed that would take full advantage of the calculator as a teaching tool, for materials to teach estimation, significant digits, and related ideas, and for materials on new topics not presently in the curriculum, but now made feasible with the calculator.

Werner, Marijane, "The Hand-Held Calculator and It's Impact on Mathematics Curricula," School Science and Mathematics 80:29-36, January, 1980.

The author reported on three major conferences, all sponsored by national mathematics groups, that were created to sort out the issues surrounding hand-held calculators and to give direction to the mathematics community for adjusting to the existence of calculators. From one of these conferences, the NIE and NSF sponsored Conference on the Uses of Hand-Held Calculators in Education in Arlington, Virginia, June 26-30, 1976, came the Report of the Conference on Needed Research and Development on Hand-Held Calculators in School Mathematics. Of particular importance to this investigator were several recommendations given by this report in the area of dissemination. The report defined a need to rapidly communicate results of calculator experiments and proposals for their use to teachers, and it stated that evaluations of calculator-based materials must be readily accessible to teachers. "Research and curriculum development must proceed hand in hand" (:36).

Hill, Shirley, "Issues From the NACOME Report," Mathematics Teacher 69:440-446, October, 1976.

Hill, chairman of the NACOME committee, outlined the committee's report and detailed some of the important points with respect to the mathematics curriculum. NACOME recommended "that beginning no later than the end of the eighth grade, a calculator should be available for each mathematics student during each mathematics class. Each student should be permitted to use the calculator during all of his or her mathematical work, including tests"(:443). Hill expressed concern over the increasing amount of elementary mathematics teaching devoted simply to developing computational facility especially in light of the widespread availability and use of calculators. The author recommended that the scope and sequence of the elementary mathematics curriculum be revised to emphasize decimal numeration for calculator arithmetic; and that greater attention be placed on estimation than on exact answers from paper-and-pencil algorithms, to enable students to better judge reasonableness of calculator answers.

SUMMARY

Research on hand-held calculators is relatively new. Studies first began to appear around 1974, with a flurry of research being reported in 1976. Suydam stated that over 100 studies had been conducted between 1978 and 1979. Before the emergence of the electronic calculator, a few studies had been conducted with the hand-operated computing machine. Fehr, McMeen, and Sobel carried out a four and one-half month experiment with fifth graders. The authors reported that the computing machines increased paper-and-pencil computation and reasoning ability. Significantly better attitudes toward arithmetic were also exhibited.

This investigator reviewed twenty-two studies involving the use of calculators. Thirteen of these focused on computational and/or attitudinal effects of using calculators, and nine on problem-solving effects. The typical research design was pretest/posttest. The studies were generally of short duration (four to ten weeks) and involved two treatment groups: an experimental group who was allowed to use calculators during the instruction period and a control group who was not.

In the studies involving the effect of calculator use on computation and attitude, subjects tested ranged in grade level from kindergarten to ninth grade, with most of the studies carried out at the fifth and sixth grade level. Four of the studies involved low-achieving students, most of

whom were at least two years below grade level. In all but two of the thirteen studies calculators were not allowed to be used on the pre- or posttests.

In a study of sixty students enrolled in a summer remedial program, Schnur and Lang reported significant gains in computational ability on the part of the experimental group. Whitaker concluded from a study with first graders that instruction using calculators is no less effective than instruction without in terms of overall mathematical achievement and attitude gain. Paasonen , in a study which took place in a Finnish comprehensive school, found that the lowest-ability group profited more from calculator use than the others. In a year-long study of considerable magnitude in terms of numbers of subjects and experimental sites (1500 students in grades 2 to 6 from five different states) Shumway discovered no detrimental effects for teaching mathematics associated with calculator use, and students did show improvement in their attitude toward mathematics. Creswell reported significant differences in achievement in favor of the experimental group who used calculators along with specially designed curriculum materials. Cech revealed that the use of calculators did not improve computional skills or attitude. It should be noted that in this study calculators were used only to verify paper-and-pencil computation. This practice is of questionable value (Reys:39).

Two studies involved the use of programmed-feedback calculators. West found paper-and-pencil strategy more effective than a programmed-feedback device in teaching basic multiplication facts. According to Standifer and Maples, both hand-held calculator and programmed-feedback calculator were superior to the no-calculator approach in the learning of computational skills.

Overall, seven of the thirteen computational studies cited indicated significant gains in computational skills and three indicated improvement in attitude associated with calculator use. The remaining studies reported no negative or positive effects from calculator use.

Research involving the effects of calculator use on problem-solving ability is not as abundant. Of the nine studies reviewed by this investigator, four were carried out through the medium of doctoral dissertations. The most frequently tested grade level was grade six. Three of the studies involved students with above average ability. In one study over 50 percent of the subjects were above the ninetieth percentile in mathematics achievement. In four of the studies students in the experimental group were allowed to use calculators on the posttest.

According to Wheatley, subjects in the experimental group used significantly more problem-solving processes, while subjects in the control group committed over twice as many computational errors. These results suggested that

calculators allowed students to focus more on problem-solving strategies and less on computation. Lowerre came to a similar conclusion. Blume and Mitchell demonstrated that a significant association between the choice of a longer solution method and hand-held calculator use. Another finding was that paper-and-pencil produced more computational errors, whereas calculators produced more errors involving chaining of operations. Anderson pointed out that on untimed tests, students using calculators correctly solved problems twice as fast as those not using calculators. According to Kasnic, an analysis of practice sessions revealed that groups using calculators did not solve significantly more problems than the group without calculators. Boling reported no significant differences in problem-solving ability between treatment groups when the experimental group used calculators to perform all computations. Vannata identified significant gains in problem-solving performance on the part of the experimental classes. It should be noted that the teachers of these classes were provided with a guide correlating the use of the hand-held calculator with the classroom mathematics text and other calculator-oriented materials.

Overall, five of the nine problem-solving studies cited indicated significant gains in problem-solving ability associated with calculator use. The remaining studies reported no negative or positive effects from calculator use.

Carpenter and others summarized the results of the second NAEP mathematics assessment. Data revealed that thirteen-year-olds are not proficient in using complex algorithms, although great amounts of time are spent teaching these algorithms. Data also revealed that the greatest single lack at all grade levels was problem-solving skills. Students using calculators scored significantly higher in computation at all grade levels tested, but performance was poorer on test items requiring problem-solving techniques. These data raise the question as to whether paper-and-pencil algorithms should continue to be taught in school, and point out a need to teach problem-solving strategies that take full advantage of the calculator.

According to Wyatt et al., in an extensive survey conducted in Missouri, almost 70 percent of the students had access to al least one calculator for school use. Over 80 percent of the teachers thought calculators should be made available to students in school, even though most teachers were unaware, or wary of the effects of calculator use on children's ability to compute. No teacher was even familiar with what research had been done on calculators. Shumway reported that the greatest doubts raised by parents and teachers alike regarded the possible negative effects of the hand-held calculator on the ability and willingness to perform paper-and-pencil computations. Calculator proponents argued that the calculator will enable educators to shift their

focus from how to compute to when and what operation to use. Pollak urged mathematics educators to consider what are some of the most difficult problems encountered in teaching school mathematics which could be helped by the calculator. Gawronski and Coblentz stated that low cost and availability alone do not justify using calculators in the classroom, and that students must command some minimal level of computational skill independent of machine support. Usiskin pointed out that the critical issue is not how the computation is done, but rather knowing when and what arithmetic to solve problems; and therefore questioned the current practice of requiring all students to learn paper-and-pencil algorithms.

Mathematics educators have seriously considered the role of calculators in teaching mathematics. As early as 1974, national mathematics groups issued calls for exploring the use of calculators in classrooms and held conferences to give direction to the mathematics community for adjusting to the existence of calculators. Out of these conferences came reports containing recommendations for calculator implementation, calls for research, and materials, resources and strategies for teachers. Werner in reporting on three major conferences, identified a need to rapidly disseminate results of calculator experiments and evaluations of calculator-based materials to teachers.

CONCLUSIONS

In all the studies reviewed, computational scores were as high or higher for groups using calculators during instruction than for groups not using them. There seemed to be enough evidence to believe that calculators are not detrimental to computational skills and that calculators are more likely to improve such skills when used along with specially designed curriculum materials.

In regard to attitude, children do not suffer from using a calculator. Differences reported were always favorable toward the experimental group using calculators. Unrestricted calculator use (where calculator use is not limited to verifying paper-and-pencil computation) is more likely to contribute to positive attitudes toward mathematics.

Results regarding the effect of calculator use on problem-solving performance are inconclusive. There is too little evidence to support the belief that calculators allow students to focus more on problem-solving strategies and less on computation. Unless problem-solving strategies are taught along with the use of calculators, benefits accrued from the use of calculators will be nominal.

For the most part, teachers are unaware of what research has been done on calculators. Results from experimental studies and proposals for calculator use have not been effectively communicated to teachers. Calculator

curriculum development has been retarded because of poorly disseminated research.

RECOMMENDATIONS

It is recommended that:

1. Estimation, mental arithmetic skills, and decimals be taught earlier in elementary school in place of time spent on the teaching of division (multiple-digit divisor) and other complex algorithms.
2. Calculator materials be developed correlating the use of the hand-held calculator with the classroom mathematics text and the local mathematics program, and that these materials be effectively disseminated to teachers and used with calculators.
3. Instruction in problem-solving strategies accompany calculator use.
4. Calculator research be rapidly communicated to the school and community.
5. Long-term research of the cross-sectional or longitudinal design be done to determine the timing for introducing calculators into the mathematics curriculum and to determine the ordering of topics within the curriculum.

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